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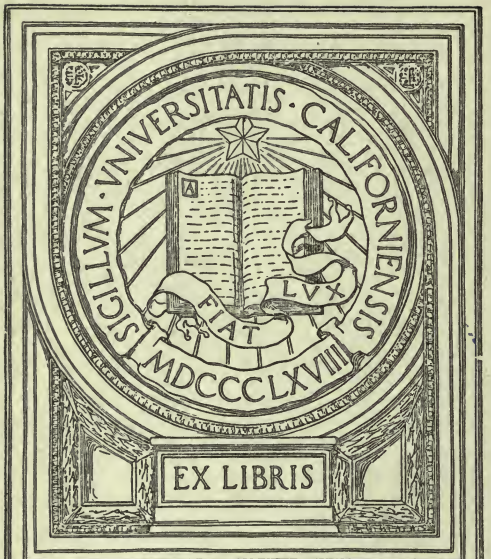
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MANNHEIM

AND

MULTIPLEX SLIDE RULES

By

L. W. ROSENTHAL

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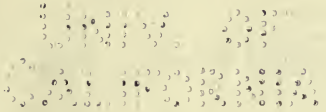

Theory and Practical Application

By

L. W. ROSENTHAL

Elec. Eng. Assoc. A. I. E. E.

Inventor and Patentee of the Multiplex Slide Rule

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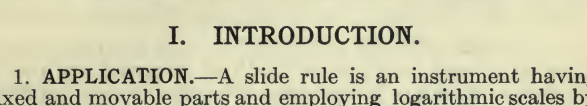
PART I.

THE MANNHEIM SLIDE RULE

Part I—Mannheim Slide Rule



I. INTRODUCTION.

1. **APPLICATION.**—A slide rule is an instrument having fixed and movable parts and employing logarithmic scales by means of which arithmetical, algebraic and trigonometrical calculations may be performed mechanically. Thus the instrument is applicable to nearly all forms of calculation, and owing to these properties it is becoming recognized with increased rapidity in almost all branches of commerce and engineering. Although slide rules have been employed by professional men for a comparatively short time, yet their service in many directions is so clearly marked that their use is now demanded in many places. To the active engineer and student the slide rule is invaluable, while the merchant, manufacturer, accountant, statistician and almost everyone connected in any way in a business undertaking will find in it an instrument of material service and accuracy. In the following text an attempt has been made to include all that is useful in a slide rule to the engineer and student. Other readers will find it necessary to understand only those parts of the book dealing with the ordinary examples of multiplication, division and proportion.

2. **QUALIFICATIONS.**—Let the reader clearly understand at the outset that the principles which underlie the theory and practical application of the slide rule are so few and so simple that its proficient use may be easily understood and mastered by almost everyone. The theory of the slide rule lies in the elementary principles of logarithms and its practical application is reduced to the ability required for reading graduated scales.

3. **ACCURACY.**—The degree of exactness to which results may be found depends upon the skill of the operator, the length of the scales and the accuracy of their division. Proficiency in setting and reading comes naturally to the operator together with confidence and certainty in the results. The principles upon which the slide rule is based are infallible, but a slight error enters into computations involving numbers of many figures, due to the fact that interpolation is then necessary in setting and reading. Roughly speaking, the accuracy obtainable with the common ten-inch slide rule is equivalent

to that of a three-place logarithmic table, while a rule twenty inches long will generally add another figure to the results. This degree of precision is sufficient for almost all engineering calculations and is of material value, at least as a certain check, for the most part of all other computations of an ordinary nature. With the full-length scales of the ten-inch rule, results should always be accurate within three-tenths of one per cent., while a little experience and care will better this to two-tenths and less even in rapid working. For the upper scales of the ten-inch rule the error may amount to one-third per cent., while with a twenty-inch rule it is proportionately decreased.

4. **SAVING IN TIME AND LABOR.**—The fact that the slide rule will just as readily solve problems involving any number of factors with any combination of figures in each, results in a time and labor saving device of much importance. Furthermore, it is almost as easy to multiply, divide, extract the root or raise to a power, numbers of many figures as it is to perform the same operations on those of the simplest kind. Let the reader but understand the following text and then with a little practice and concentration a considerable amount of time, labor and mental strain will be eliminated from his daily calculations.

II. THEORY OF LOGARITHMS.

5. **DEFINITION.**—To understand the theory and action of a slide rule it is necessary to be familiar with the elementary principles of logarithms. These principles are primarily based upon the fact that every number is equal to some power of every other number, the exponent or index of which power is either greater or less than one. For example, any number, as 49, is equal to any number, as 10, raised to a certain power, the exponent of the power in this case being approximately 1.69. If 10 be chosen as the fixed number which is to be raised to a power to produce any other number, then 10 becomes the base of this system, the exponent in any case being the logarithm. In general the logarithm of any number is the exponent of the power to which the base of the system must be raised to produce that number. Thus 2 is the logarithm of 100 to the base 10 since $10^2 = 100$. The whole part of the logarithm which precedes the decimal point is called the characteristic, while the decimal part following it is the mantissa. In the logarithm 1.69, 1 is the characteristic and .69 is the mantissa.

6. **COMMON LOGARITHMS.**—The system of logarithms having 10 for its base is called the common system. For this system the characteristic simply determines the position of the decimal point in the number corresponding to the logarithm, while the mantissa of the logarithm is identical for the same series of figures no matter where the decimal point in the number is placed. Therefore if the position of the decimal point

be neglected only the mantissa of the common logarithm need be considered. Herein lies the peculiar advantage of the common system of logarithms, and for this reason it is always applied to the slide rule. In the following text wherever logarithms are mentioned the common system will be understood.

7. **RELATION BETWEEN NUMBERS AND LOGARITHMS.**—As stated, the mantissa or decimal part of the logarithm in any case depends only upon the string of figures comprising the number. These mantissæ have been tabulated in many books and will be found as given in Table I.

TABLE I.

Number.....	1	2	3	4	5	6	7	8	9	10
Logarithm....	0	.301	.477	.602	.699	.778	.845	.903	.954	1.000

The logarithm of any number composed of 2 and as many zeros as you please will always have .301 for its mantissa, but its characteristic will depend upon the number of figures before the decimal point; and similarly for any other of the above numbers.

8. **MULTIPLICATION.**—It will be observed from Table I that the sum of any two logarithms is the logarithm of the product of the two corresponding numbers. For example, the sum of the logarithms of the numbers 2 and 3 is .301 + .477 or .778, which is the logarithm of 6 or 2×3. Similarly the sum of the logarithms of 3, 5 and 6 is 1.954, of which the mantissa .954 is the logarithm of 9, the characteristic 1 indicating that there are two figures in the result before the decimal point. Hence their product is 90 or $3 \times 5 \times 6$. This same relation will be observed between any two or more numbers and their logarithms. Therefore by adding the logarithms of any two or more numbers the logarithm of their product is obtained, from which the product itself may be easily found.

9. **DIVISION.**—From Table I it will also be apparent that the difference between any two logarithms is the logarithm of the quotient of the corresponding numbers. The difference between the logarithms of 8 and 4 is .903 — .602 or .301, which is seen to be the logarithm of 2 or $8 \div 4$; and similarly for any two or more numbers and their logarithms. The general rule then follows that by subtracting the logarithm of one or more numbers from the logarithm of any number, there results the logarithm of the quotient, from which the quotient itself may be readily obtained.

10. **POWERS.**—If the logarithm of any number in Table I be multiplied by 2, the resulting logarithm corresponds to its second power or square. Thus the logarithm of 3 multiplied by 2 is $.477 \times 2$ or .954, which is the logarithm of 9 or 3^2. Also if the logarithm of 2 be multiplied by 3 there results .903, the logarithm of 8 or 2^3. Since this relation is true for any num-

ber to any power, the rule follows that the logarithm of a number multiplied by any factor gives as a product the logarithm of that power of the number of which the factor is the index. The power itself may then be observed.

11. ROOTS.—Again referring to Table I, it will be seen that by dividing the logarithm of any number by 2, the logarithm corresponding to its square root is obtained. Thus the logarithm of 9 divided by 2 is .954 ÷ 2 or .477, which is the logarithm of 3 or $\sqrt{9}$. Also .903 ÷ 3 equals .301, which is the logarithm of 2 or the cube root of 8. Since the principle is similar for the fourth, fifth or any other whole or decimal root of any number, the rule may be stated that by dividing the logarithm of any number there is obtained the logarithm of its root of which the divisor is the index. The root itself may then be found.

12. APPLICATION TO SLIDE RULES.—It has been seen that the processes of multiplication and division reduce to the addition and subtraction of logarithms. Hence if an instrument is produced which is capable of mechanically adding and subtracting these logarithms, it may perform all computations of multiplication and division. Likewise the second or third powers and roots may be mechanically determined if the instrument is capable of multiplying and dividing the logarithms by 2 or 3.

The slide rule accomplishes these results by applying the principles of logarithms. Instead of tabulating the logarithms, the slide rule carries them in the form of scales or graduated lengths, each unit length representing equal parts of the logarithmic table. Thus if the logarithm of 10 be chosen as the unit, then the logarithm of 2 or .301 will be represented by .301 of that unit; 3 by .477 of the unit; 4 by .602; and so on, as can be determined from Table I. The numbers between 1 and 2, 2 and 3, 3 and 4, etc., are represented on this logarithmic scale by intermediate divisions, the entire scale being graduated as closely as is convenient for reading. It will be observed however, that the values of the logarithms themselves are not shown on the scales, but instead will be found the numbers corresponding to those logarithms. At $\frac{301}{1000}$ th part along the scale on the slide rule will be found 2, not .301; similarly at the $\frac{845}{1000}$ th part is found 7; the result of which is that the process of finding the numbers corresponding to the logarithms and vice versa is entirely eliminated from all calculations.

III. MECHANICAL CONSTRUCTION.

13. MECHANICAL PRINCIPLES.—If two ordinary scales be drawn so that their divisions are equal throughout, the

sum of any number of units of one scale and any number of the other may be determined mechanically. In Fig. 1, any

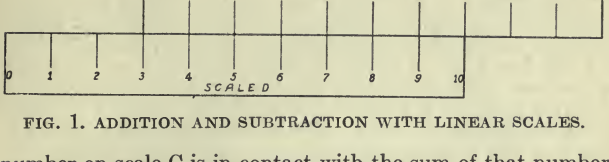


FIG. 1. ADDITION AND SUBTRACTION WITH LINEAR SCALES.

number on scale C is in contact with the sum of that number and 3 on scale D. Thus 3 of C and 6 of D are opposite one another, and similarly for 4 and 7, 5 and 8, and so on for the full range of the scales. Conversely for subtraction, any two numbers whose difference is 3 will be found in contact on C and D. Furthermore, if scale C be turned upside down with respect to D, it is evident that the above conditions for addition and subtraction are reversed.

These principles will be obvious to the reader and embody everything that is necessary to understand the mechanical principles of the slide rule. It will be remembered, however, that in adding the logarithms of numbers, the logarithm of their product results; and in subtracting them the difference is the logarithm of the quotient. Furthermore, the graduations on the scales of the slide rule are not equally spaced since the numbers are noted and not their logarithms. The features of mechanical construction of the slide rule adopted by the Eugene Dietzgen Co. so as to best accomplish these results will be found in the following paragraphs.

14. **BODY.**—The slide rule is composed of three separate parts, the body, slide and runner, the first two being made of well-seasoned and especially selected wood. The body is the fixed part, consisting of a base upon which are rigidly mounted two graduated rules made exactly parallel to each other and separated by an opening for the reception of the slide. The rules are faced with celluloid and have logarithmic scales engraved upon them. The under side of the base carries a table of constants for reference, while along the opposite sides are the ordinary scales of inches and centimeters for linear measurements.

15. **SLIDE.**—This is a comparatively thin slip of wood faced on the top and bottom with celluloid upon which logarithmic scales are engraved. Along each edge of the slide is an extended tongue which accurately fits corresponding grooves in the body of the rule. This construction allows the slide to move lengthwise within the base in either normal or inverted position and with either face uppermost. The scales of the fixed rules and slide should lie absolutely in one plane and no appreciable opening should appear at the contact edges of the

scales for any position of the slide. Furthermore, the slide should move just freely enough so as to neither bind nor stick and still be secure in every position.

16. **RUNNER.**—The runner is formed of a small aluminum frame enclosing a piece of glass. On the underside and along the center of the glass, lying almost in contact with the scales, is a fine hair-line. The runner slides in grooves on the sides of the base, while a spring on one side permits free movement along the length of the rule, but always holds the hair-line truly at right angles to all scales. The hair-line should be about as heavy as the scale graduations, and uniform throughout its length. The runner is used for settings and for referring from one scale to the other; it also eliminates the necessity of reading intermediate results in a continued series of calculations.

17. **LENGTH OF RULES.**—Slide rules are made by us in three standard sizes, the full length of the logarithmic scales being 12.5, 25 and 50 centimeters respectively. The rule almost invariably used, however, has the 25-centimeter scale and is popularly known as the ten-inch slide rule. This length best combines accuracy and convenience, although the twenty-inch size is more accurate and the five-inch more convenient to carry around. The stock of the body and slide project a little beyond the scales in order to secure a firm setting of the slide and runner at either end.

18. **GRADUATION OF SCALES.**—The scales of our rules are engine divided and engraved, the divisions being automatically spaced by means of a logarithmic screw. This process results in scales of highest accuracy and greatest durability. The lines are black on a clear white celluloid background, thus producing a reading surface of considerable merit.

19. **CARE OF RULES.**—It is important that slide rules be kept in places where excessive or rapid changes of temperature or humidity are not likely. All varieties of wood and celluloid are liable to shrink and warp under unfavorable conditions, and when such does occur the instrument will become unsatisfactory in operation. Always keep your rule away from radiators and damp places.

20. **METHOD OF OPERATION.**—It has been found most convenient and accurate to operate with the slide rule flat down on a table. The projecting end of the slide should be held along both tongues at the end of the base, between the thumb and index finger. The index finger of the other hand should be kept between the fixed rules and against the end of the slide, with the thumb and middle finger of that hand along the sides of the base. The slide may then be easily and gradually moved between the fingers of the first hand, which are capable at any time of reducing, stopping or reversing the motion of the slide. The operator will appreciate this method after a little practice with the rule.

IV. NOTATION OF SCALES.

21. **DESIGNATION OF SCALES.**—There are six complete logarithmic scales on both the fixed rules and the upper face of the slide. The upper fixed rule carries two scales which are identical with the two engraved along the upper edge of the slide. Along the lower edge of the slide and the lower fixed rule are two complete scales. The upper scales are usually designated A and B, while the lower ones are marked C and D, as shown in Fig. 2. Scale A includes the two complete logarithmic scales A′ and A″, while B includes B′ and B″. The initial graduations at the left-hand end of the scales A, B, C and D are each termed the left index of its respective scale, while the corresponding lines at the right-hand end are the right indices. The middle graduations of scales A and B are called their center indices.

22. **RELATION OF DIVISIONS.**—Each logarithmic scale is laid off from its left index, which being the starting-point is marked 1, since the logarithm of 1 is 0. (See Table I.) Each other number is represented by the same part of the chosen unit length as its logarithm bears to the logarithm

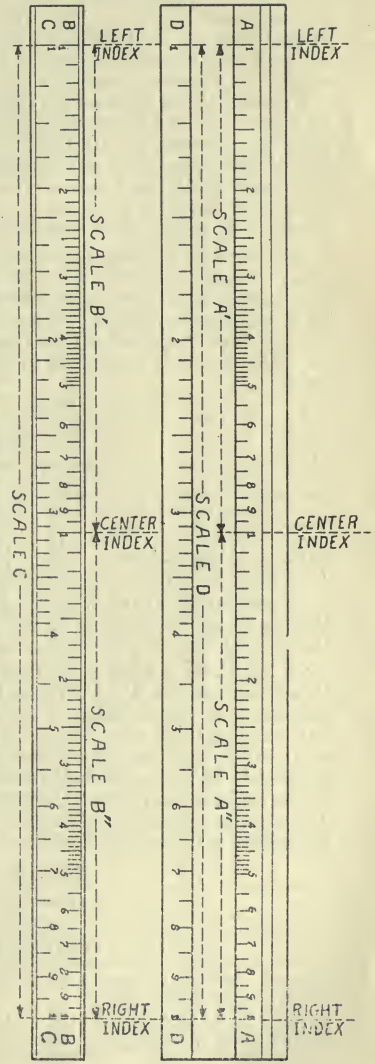


FIG. 2. DESIGNATION OF SCALES AND INDICES.

of the chosen unit. Then since 10 is taken as the unit, the number 2 will be found at the distance .301 from the left index of the scale; 3 is located at .477; 4 at .602; and similarly for every other number. In this way the complete logarithmic scales are laid out, it being observed that each number is represented by a certain length in terms of the length of the scale.

From what has been said in reference to the common system of logarithms it will be apparent that the left index of any scale may represent 1, 10, 100, .1, .01, .001, etc., in which cases the division marked 2 will represent 2, 20, 200, .2, .02, .002, etc., respectively; and similarly for all other numbers. Simply remember that the divisions marked 2, 3, 4, etc., are respectively 2, 3, 4, etc., times the chosen value of their left index.

23. **SCALES C AND D.**—These scales are similar to each other in every respect. In order that they may be graduated as minutely at all parts as is convenient to read, it is necessary to have three different values for their smallest divisions. With the left-hand index equal to 1, the values of all divisions on scales C and D are shown in Table II for the three sizes of rules.

TABLE II.

	FIVE AND TEN-INCH RULES.			TWENTY-INCH RULE.		
	1 TO 2	2 TO 4	4 TO 10	1 TO 2	2 TO 5	5 TO 10
Value of each main division	1.00	1.00	1.00	1.000	1.00	1.00
Value of each minor division	.10	.10	.10	.100	.10	.10
Value of smallest division	.01	.02	.05	.005	.01	.02
Total number of divisions	100	100	120	200	300	250

In general the C and D scales are used for the simple calculations where accuracy is desired, this feature resulting from the greater length and subdivsion of those scales.

24. **SCALES A AND B.**—These comprise the four complete logarithmic scales A′, A″, B′ and B″ on the upper fixed rule and along the upper edge of the slide. Each is exactly one-half the length of that of the C or D scale, the left indices of A′ and B′ and the right indices of A″ and B″ being engraved accurately in line with the left and right indices respectively of the lower scales. The values of the divisions of each of the upper scales are shown in Table III for the five, ten and twenty-inch rules with their left index equal to 1.

TABLE III.

	FIVE AND TEN-INCH RULES.			TWENTY-INCH RULE.		
	1 TO 2	2 TO 5	5 TO 10	1 TO 2	2 TO 4	4 TO 10
Value of each main division	1.00	1.00	1.00	1.00	1.00	1.00
Value of each minor division	.10	.10	...	.10	.10	.10
Value of smallest division	.02	.05	.10	.01	.02	.05
Total number of divisions	50	60	50	100	100	120

On scales A′ and B′ will be found a graduation at 3.1416 which is marked π in each case, and on scales A″ and B″ is located .7854 or $\pi \div 4$. Those constant demarcations are for convenience in the frequently recurring calculations of areas and diameters of circles. Scales A and B are usually employed for computations where rapidity in working is the main consideration, and for finding powers and roots.

25. **READING SCALES C AND D.**— For rapid working with the slide rule it is necessary that the operator be accurate and confident in his settings and readings of the various scales. The C and D scales are divided and subdivided as shown in Table II, and for further figures it is necessary to estimate the decimal part of the smallest divisions by the eye. Various examples of settings and interpolations appear in Fig. 3, along different parts of the scale of a ten-inch rule and with the left index taken equal to 1,000. Besides these, the reader should make the following and many other settings and readings, using both the upper and lower scales: Set 8 on C to 17 on D and read 2.125 on D at the right index of C; set 4 on C to 53 on D and at the left index of C read 13.25 on D; set 68 on C to the right index of D and by means of the runner read 8.25 on D at 561 on C.

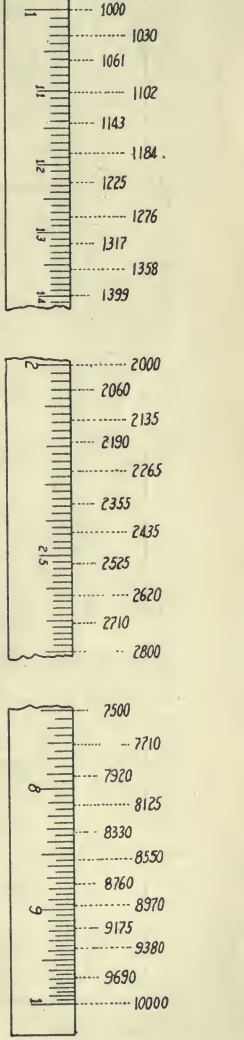


FIG. 3. READINGS ON SCALE C OR D OF A TEN-INCH SLIDE RULE.

26. **READING SCALES A AND B.**— The values of the various divisions on these scales are given in Table III, and are seen to differ from those of the lower scales. Various readings along the upper scales are shown in Fig. 4 (see page 16) for a ten-inch rule, and after these have been carefully compared the reader should make many other settings and readings both with and without the runner, until he is thoroughly familiar with all parts of the upper and lower scales.

27. **TEST OF ACCURACY OF DIVISION.**— Although our scales are

accurately divided the reader should make an absolute test on all scales. First set the left indices of scales C and D together and note that all other corresponding indices and graduations are in exact contact. Then by means of the runner see that the four left indices are exactly in line and similarly for the four right indices, which process will simultaneously check the alignment of the hair-line of the runner. Now set 2 on scale C to the left index of D and note that all graduations between 2 and 4 on scale C exactly coincide with the graduations on D between 1 and 2. Then set 4 on C to 8 on D and observe exact coincidence of divisions from 4 to 5 on C with 8 to 10 on D. Finally set 5 on C to the left index of D and see that all divisions between 5 and the right index of C are in absolute contact with graduations of scale D.

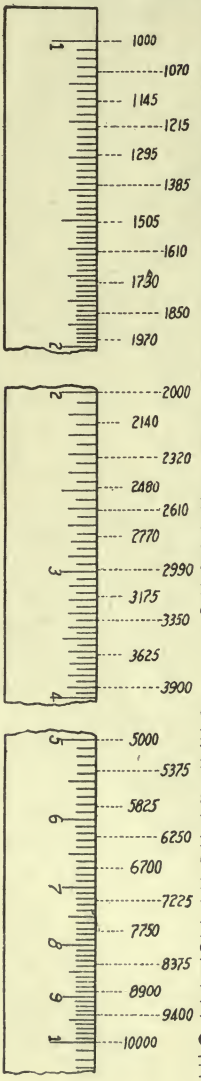


FIG. 4. READINGS ON SCALE A OR B OF A TEN-INCH SLIDE RULE.

To completely check scales A and B, set the left index of B′ to the left index of A″ and observe alignment of all corresponding graduations throughout these scales. Then set 2 on B″ to 4 on A′ and note contact for all divisions between 2 and the right index of B″.

V. MULTIPLICATION.

28. **TWO FACTORS.**—It has been explained that the sum of the logarithms of two or more numbers is the logarithm of the product of those numbers; also the logarithms of numbers are mechanically added by means of the slide and fixed rules. Hence to multiply any two numbers, using scales C and D, one index of C is set directly above either f ctor on D and under the other factor on C is read their product on D. This statement may be expressed in tabular form as below for both the C and D scales and A and B, the latter including A′ or A″ with either B′ or B″.

C / D	Set 1 / to one number	At other number / read product	B / A

It will be observed after choosing any set of values that but one of the two indices of C can be used with D for any given case. If 25 is to be multiplied by 31, the left index of C must be set to either 25 or 31 in order that the other factor on C will be above scale D; and if 635 is to be multiplied by 2, the right index of C must be used in order to read their product 1270 under scale C. The following examples should be solved, using both the upper and lower sets of scales, and then checked by multiplying the factors out by hand:

C	Set 1	At 25	B
D	to 636	read product 15900	A

C	Set 1	At 3	B
D	to 259	read product 777	A

With the slide projecting on the right the logarithm of one factor on one scale is added to the logarithm of the other factor on the other scale, but if the slide projects on the left of the rule, 10 minus the logarithm of the factor on the slide is subtracted from the logarithm of the factor on the fixed rule. However, the results of these two operations are exactly equivalent, since for the latter case

$$\log. a - (10 - \log. b) = \log. a + \log. b - 10,$$

wherein a and b represent any two numbers while 10 is the value of the full scale length.

29. **ALTERNATIVE METHOD.**—The following method of multiplication is sometimes convenient, although the preceding form is usually adopted:

C	Set one number	read product	B
D	to 1	At other number	A

In the above the logarithms of the two numbers are added together, but in a different way from the method of paragraph 28.

30. **CONTINUED MULTIPLICATION.**—The process of multiplying more than two numbers together is exactly similar to the method for two factors, the product of the first two being in turn multiplied by the third number, and that product by the fourth, and so on. In such cases it will be found necessary to use the runner in order to avoid reading off the intermediate products. The following tabular statement for the multiplication of three factors will be apparent:

C	Set 1	Runner to second number	1 to runner	At third number	B
D	to first number			read final product	A

31. **CONSTANT MULTIPLIER.**—By setting the index of C to any number on D, all products of the factor on D with all numbers in contact on C may be read off directly without resetting the slide. This property of the slide rule is often convenient in a series of multiplications having a constant factor.

For such problems it is generally preferable to use A and B, since complete scales are always in contact, thus eliminating the necessity of shifting the slide, as may be required for the lower scales.

32. **DECIMAL POINT.**—The string of figures in the product having been determined, it then becomes necessary to locate the decimal point. It is always advisable for the operator to mentally check the problem, thus locating the decimal point at the same time, which in many cases may be done by inspection. However, rules will be given which are simple and cover all cases of multiplication. First it must be understood that the digits in any number greater than 1 is the same as the number of figures preceding the decimal point, while for numbers less than 1, the digits are minus and equal to the number of zeros which directly follow the decimal point. Thus 2.693 has one digit; 149.06, three digits; 14836, five digits. For decimal numbers .103 has zero digits; .09, minus one digit; .0000238, minus four digits. Where there are more than two factors to be multiplied each setting is to be considered separately. The following rules apply only to the common method of multiplication as outlined in paragraph 28, while for the alternative method of paragraph 29, the rules for the decimal point are reversed.

FOR SCALES C AND D ONLY.

WITH THE SLIDE PROJECTING ON THE LEFT, the number of digits in the product is equal to the sum of the digits in the two factors.

WITH THE SLIDE PROJECTING ON THE RIGHT, the number of digits in the product is equal to one less than the sum of the digits in the two factors.

In applying these rules to a decimal factor, remember that subtracting from a minus number of digits increases the number of negative digits, while adding to it has the opposite effect. For example, 2 subtracted from —3 digits is —5 digits, and 2 digits added to —3 is —1 digit.

The position of the decimal point may be determined for all scales and methods by remembering that where the first significant figure of the product is less than the first significant figure of both factors, or equal to it, in which case the succeeding figures are to be likewise compared, the number of digits in the product is equal to the sum of the digits of the two factors; and where it is greater the digits in the product is one less than their sum. By the first significant figure is meant the first figure from the left other than zero. The first significant figure of 309.6 is 3, and of .00298 is 2.

33. **EXAMPLES.**—The following examples are appended so that the reader may become familiar with the process of multiplication and the location of the decimal point. The solu-

tions are shown for the C and D scales, but scales A and B should also be used by the reader for each problem.

EXAMPLES	SUM OF DIGITS	NO. OF TIMES SLIDE PROJECTS ON		DIGITS IN PRODUCT	ANSWER
		LEFT	RIGHT		
55×4.6	3	1	0	3	253
$.00039 \times 1.41 \times 41.5$	0	1	1	−1	.0228
$4.75 \times 1.28 \times 83.3 \times .0351$	3	2	1	2	17.78
$.0017 \times .029 \times .111 \times 68$	−1	1	2	−3	.000372

VI. DIVISION.

34. **TWO NUMBERS.**—The slide rule mechanically performs division by subtracting the logarithm of the divisor from that of the dividend. Using the C and D scales, the process consists in setting the divisor on C over the dividend on D and under one index of C finding the quotient on D.

C	Set divisor	At 1	B
D	to dividend	read quotient	A

Where the quotient is found at the left index of either C or B the logarithms are subtracted directly, but by using the right index, 10 minus the logarithm of the divisor is added to the logarithm of the dividend, which, however, is exactly equivalent to the first case, since

$$\log. a + (10 - \log. b) = \log. a - \log. b + 10,$$

wherein a is the dividend, b the divisor and 10 the value of the unit scale length.

The reader should perform the following divisions, using in turn all sets of scales, and then check the answer by hand:

C	Set 81	At 1	B	C	Set 26	At 1	B
D	to 28500	read quotient 352	A	D	to 4550	read quotient 175	A

35. **ALTERNATIVE METHOD.**—It is sometimes convenient to divide in the following manner, using either pair of scales, as shown:

C	Set divisor	At dividend	B
D	to 1	read quotient	A

The principle of this method is entirely analogous in results to that of the preceding.

36. **CONTINUED DIVISION.**—This operation consists of a series of divisions, the runner being used to avoid reading off

the intermediate quotients. In tabular form the process for two divisions is as follows:

C	Set first divisor	Runner to 1	Second divisor to runner	At 1	B
D	to dividend			read final quotient	A

37. **RECIPROCALS.**—The reciprocal of a number is equal to 1 divided by the number. Thus the reciprocal of 4 is .25; of 500 is .002; and of .0625 is 16. The process is simply one of division, and may be performed by either of the following methods, using either set of scales:

C	Set number	At 1	B
D	to 1	read reciprocal	A

C	Set 1	read reciprocal	B
D	to number	At 1	A

Although the method is seldom used, the above principles may be applied to division as follows:

C	Set dividend	read quotient	B
D	to divisor	At 1	A

By this process the divisor is divided by the dividend and the reciprocal of that quotient found, all at one setting and with any pair of scales.

38. **CONSTANT DIVIDEND.**—With the ordinary position of the slide, such problems are best solved by bringing the runner to the constant number on D and successively setting the divisors on C to the hair-line. The quotients are read in turn on D under the index of C.

39. **CONSTANT DIVISOR.**—Much time is saved in problems of this kind by multiplying the reciprocal of the constant divisor by the series of dividends. The entire set of quotients may then be read off without shifting the slide. Where the accuracy of the upper scales is sufficient, they should generally be used so that all numbers will be in contact for any position of the slide. This method of solution is indicated below:

C	Set constant divisor	At dividends	B
D	to 1	read quotients	A

40. **DECIMAL AND COMMON FRACTIONS.**—Common fractions may be converted into decimals by dividing the numerator by the denominator according to the ordinary method of division. Decimals may be changed to common fractions by setting 1 on the slide to the decimal and finding two numbers in exact contact. If the common fraction is to

have a certain denominator or numerator, the corresponding numerator or denominator respectively, is then found in contact with the given term.

41. **DECIMAL POINT.**—After the string of figures in the quotient has been determined, the decimal point may be located for the method of paragraph 34, by the following:

FOR SCALES C AND D ONLY.

WITH THE SLIDE PROJECTING ON THE LEFT, the number of digits in the quotient is equal to the digits of the dividend less the digits of the divisor.

WITH THE SLIDE PROJECTING ON THE RIGHT, the number of digits in the quotient is equal to one more than the digits of the dividend less the digits of the divisor.

The decimal point may be located in a quotient for any method and either set of scales from the fact that where the first significant figure of the divisor is greater than that of the dividend, the number of digits in the quotient is equal to the digits of the dividend less those of the divisor. If the first significant figure of the divisor is less than that of the dividend, then one digit must be added to this difference. Where the first significant figures are the same the following figures must be compared, as in the case of multiplication.

42. **EXAMPLES.**—The reader should solve the following problems, using both sets of scales in turn:

DIVIDEND	FIRST DIVISOR	SECOND DIVISOR	THIRD DIVISOR	DIFFERENCE OF DIGITS	NO. OF TIMES SLIDE PROJECTS ON		DIGITS IN QUOTIENT	ANSWER
					LEFT	RIGHT		
546	32.9	....	....	1	0	1	2	16.6
182.9	11.11	.0042	....	3	1	1	4	3920
.0458	.1746	7.21	1.246	—3	1	2	—1	.0292
.387	.938	4.94	.0333	0	2	1	1	2.51

VII. PROPORTION.

43 **DEFINITION.**—Proportion is an equality of ratios. The statement that 3 is to 6 as 4 is to 8 is a proportion in which 3 bears the same relation to 6 as 4 does to 8. The solutions of problems in proportion for any of the unknown quantities are examples in combined multiplication and division, and are most conveniently and readily solved with the slide rule.

44. **DIRECT PROPORTION.**—The general form is

1st term: 2d term:: 3d term: 4th term.

From well-known principles the product of the two outer terms, 1st and 4th, equals the product of the two inner terms,

2d and 3d In examples of this kind three of the quantities are given and the remaining term is determined from the following:

C	1st term	3d term	B
D	2d term	4th term	A

If one of the terms equals 1, then the process reduces to simple multiplication or division of the other two numbers.

By setting two terms together as indicated above, it will be noted that all other numbers which bear the same relation are in contact. As an example consider the following: At the rate of 60 miles in 2 hours, how far will a train travel in 15 hours? 25 hours? 30 hours?

C	Set 2 hours	At 15 hours	At 25 hours	At 30 hours	B
D	to 60 miles	read 450 miles	read 750 miles	read 900 miles	A

It will be observed that 60 is first divided by 2 and the quotient found at one index of the slide, which is the required setting for the multiplication of this quotient by any number within the range of contact. In a similar manner any problem in the form of $\frac{a \times b}{c}$ may be solved with one setting of the slide.

45. **INVERSE PROPORTION.**—Where more requires less or less requires more, there exists an inverse form of proportion. With the ordinary position of the slide, such problems are solved similarly to examples in direct proportion, provided the problem is stated inversely so that the product of the outer terms is equal to the product of the inner terms. For instance, assume that 8 men perform a piece of work in 3 days, how long will it take 6 men working at the same rate to do the same work? This is a case of inverse proportion in which having less men requires more time; or in inverse form

C	Set 8 men	find 4 days	B
D	to 6 men	At 3 days	A

46. **SOLUTION OF $\frac{a}{b} \times x$.**—Problems of this kind wherein a, b and x represent any numbers whatsoever, are cases of proportion, and may be solved in a single setting by the following method:

C	Set b	At x	B
D	to a	read answer	A

If in a set of calculations a and b are each constant numbers and x has a series of values, this setting will be found convenient, especially if scales A and B are used.

In using a constant multiplier, as is given in the conversion ratios to follow and on the back of the rule, a simple and equivalent ratio is noted, rather than the multiplier itself which is usually a long decimal. For example, instead of stating that the diameter of a circle multiplied by 3.1416 equals its circumference, the relation between diameter and circumference is given as 226 : 710, since the quotient of these numbers very closely equals 3.1416, and since they are points of graduation on scales C and D. The determination of any circumference from its diameter, or vice versa, is then as follows:

C	Set 226	At diameter	B
D	to 710	read circumference	A

47. **SOLUTION OF** $\frac{a \times b \times c}{d \times e \times f}$.—Problems in this form are solved by a series of multiplications and divisions. However, instead of multiplying the factors of the numerator together and then dividing in turn by the quantities in the denominator, greater rapidity is usually obtained by the following method:

C	Set d	Runner to b	e to runner	Runner to c	f to runner	At 1	B
D	to a					read answer	A

48. **DECIMAL POINT.**—The decimal points in the preceding problems are located by the principles for multiplication and division, each operation being considered separately. The following method of keeping record in multiplication and division is recommended for long problems: For each time that an extra digit is to be added the sign | is noted, and for each time an extra digit is to be subtracted the sign — is set down, the two opposite signs being allowed to cancel each other as far as they will. In the problem $\frac{.042 \times 36.9 \times 147}{32.6 \times .00186 \times 232}$, performed on the C and D scales, the slide projects on the right twice in multiplying and three times in dividing, giving the record + + |, which indicates that the answer contains one more than the digits of the numerator less those of the denominator. Hence the final answer has $(-1+2+3)-(2-2+3)+1$ or 2 digits, and equals 16.2.

VIII. POWERS AND ROOTS.

49. **RELATION OF UPPER AND LOWER SCALES.**—Each of the upper scales is exactly one-half the length of the lower scales, and with its corresponding indices accurately in line. Hence any logarithm on the D scale multiplied by 2 equals the logarithm directly above it on A; and similarly for scales C and B. Therefore, since multiplying or dividing the logarithm

of a number by 2, gives the logarithm of the second power or root respectively, of the number, the slide rule gives a direct means of determining squares and square roots of all numbers.

50. **MULTIPLICATION, DIVISION AND PROPORTION WITH A AND B.**—The upper scales may be used for all such examples according to the methods outlined under like operations for the lower scales. In fact, the preceding text has been made general so as to apply to either set of scales. Due to the fact that all numbers are always in contact, the upper scales should be used for such examples where rapid working is desired and the greater error due to decreased length and subdivision of these scales is permissible.

51. **SQUARES.**—The squares of all numbers on D will be found directly above on A, and similarly for scales C and B.

A	read square	B
D	Over number	C

Either the runner or the index line may be used in referring from D to A, the latter giving more reliable results. The square of any number may also be found by multiplying the number by itself, preferably using the lower scales for the purpose. By any of these methods the square of 2 is seen to be 4; 5 squared is 25; $\overline{17.2}^2 = 296$; and $\overline{.0831}^2 = .0069$.

If a square is read on A′ or B′, the number of its digits is one less than twice the digits of the given number; and if read on A″ or B″, it has simply twice the digits of the number.

52. **SQUARE ROOTS.**—The method of finding square roots is exactly opposite to that for squares. However, it must be observed that any string of figures has two roots, the proper one for any number depending on its digits. The square root of a number having odd digits, as 144, 16,000 and .000,25, is found on the lower scales under A′ and B′, while for numbers of even digits, as 14.4, 1600 and .0025, the root is under A″ and B″.

FOR A NUMBER WITH ODD DIGITS			FOR A NUMBER WITH EVEN DIGITS		
A′	Under number	B′	A″	Under number	B″
D	find square root	C	D	find square root	C

The square roots of numbers may also be determined with either set of scales by setting the runner to the number and finding the number at the index of the slide which equals that on the slide under the runner.

If the square root is found under A′ or B′ the number of its digits equals (digits in given number $+1) \times \frac{1}{2}$; and for a square root under A″ or B″, its digits is simply one-half those of the given number.

53. **CUBES.**—The third power or cube of a number is best found by either of the following methods:

A		find cube
B		At number
C	Set 1	
D	to number	

A	to number	find cube
B	Set 1	
C		Over number

Rules may be stated for locating the decimal point in any cube, but it is better to determine its position by inspection of the given number.

54. **CUBE ROOTS.**—Cube roots are best found with the slide inverted, as will be shown. However, such may be determined by setting the runner to the given number on A and noting the number on D under the index on C equal to the number on B under the runner. In this way three cube roots of any string of figures may be found, the correct one in any case depending on the digits of the given number. For numbers containing $-8, -5, -2, 1, 4, 7$, etc., digits, scales A″ and B″ and the left index of C are used; for numbers of $-7, -4, -1, 2, 5, 8$, etc., digits, scales A′ and B″ and the right index of C are used; and for numbers having $-6, -3, 0, 3, 6, 9$, etc., digits, the A″ and B″ scales are used with the right index of C. There is one digit in the cube root for each period of three figures, or less in the extreme period, contained in the given number, counting from the decimal point toward the left for numbers greater than 1, and toward the right for numbers wholly decimal. As examples of these principles the cube root of 2,700 is 13.92; $\sqrt[3]{27{,}000} = 30$; and $\sqrt[3]{.000{,}27} = .0647$ It will be observed from the last case that the periods in decimal numbers indicate minus digits.

55. **HIGHER POWERS.**—The fourth power of a number is equal to the square of its square, and the sixth power is the square of its cube or the cube of its square. Other powers may be found in this way, but for those greater than the fourth it is better to use the scale of logarithms, as will be explained later. The setting for the fourth power is as follows, the decimal point being located by remembering the rules for squares:

A		find fourth power
C	Set 1	Over number
D	to number	

56. **FRACTIONAL POWERS.**—In almost all cases such powers should be solved by means of the scale of logarithms, although there are a few exceptions. The one-fourth power of a number, which is the same as its fourth root, is best determined by extracting the square root of its square root, due attention being paid to the digits in each setting.

The two-thirds power is determined by setting the runner to the number on D, and then finding the cube root of the square on A by the method of paragraph 54, or with the slide inverted, as will be shown.

The three-halves power is obtained as follows, care being taken that the answer is found under the proper scale of B:

B		Under number
C	Set 1	
D	to number	read three-halves power

57. **POWERS WITH PROPORTIONAL DIVIDERS.**—Where a series of numbers is to be raised to the same power, whether whole or decimal, this method may be found useful. Set the pair of proportional dividers so that the ratio of its openings in linear measure is equal to the exponent of the required power. Then by opening one side of the dividers from the left index to any number on the logarithmic scale, the opening of the other side measured along the same scale will give the required power.

IX. INVERTED SLIDE.

58. **RECIPROCALS.**—The slide may be turned around end for end so that scale C is in contact with A and B with D. It will be observed that the scales of the slide now progress from right to left. With this arrangement and having the indices in line, all numbers on C inverted (CI) are reciprocals of those directly below on D, and similarly for A and B inverted (BI).

59. **MULTIPLICATION AND DIVISION.**—By setting any logarithm on CI over any logarithm on D, their sum is found on D under the index of CI, and similarly for A and BI. Also the difference of logarithms is obtained by placing the index of CI over one logarithm on D and reading on D under the other logarithm on CI. Hence the following:

MULTIPLICATION.

CI	Set one number	Opposite 1	BI
D	opposite other number	read product	A

DIVISION.

CI	Set 1	Opposite divisor	BI
D	opposite dividend	read quotient	A

Where a constant quantity is to be successively divided by a series of numbers, this method of division is valuable, since all quotients may then be read off without resetting the slide.

60. **INVERSE PROPORTION.**—In such problems, sets of factors are obtained whose products are equal to each other. This operation is best accomplished with the slide inverted.

For example, how many teeth must a gear wheel have if it is to turn three hundred times per minute when engaging with another gear of 48 teeth making 50 R. P. M.

CI	Set 50 R. P. M.	Opposite 300 R. P. M.	BI
D	opposite 48 teeth	read 8 teeth	A

61. **CUBE ROOTS.**—The method with the slide inverted differs from that of paragraph 54 in that the index of the slide is set to the given number on A and the two equal numbers are found in contact on BI and D. The scales and indices to be used are the same for each of the three cases, it being kept in mind, however, that B″ now occupies the left-hand side of (BI), and that the right and left indices are to be considered as interchanged. The method of locating the decimal point is the same as given in paragraph 54.

X. COMBINED SETTINGS.

62. **LIST OF SETTINGS.**—The adaptability of the slide rule to the ordinary calculations of various forms is exemplified by the following list of useful settings, which combine the use of the upper and lower scales. Only those operations requiring a single setting, but not especially mentioned before, are given, although the list might be increased considerably by using the runner for intermediate results in the more complicated forms of problems. The reader will observe that alternative methods of procedure are possible for almost every setting, and he is urged to become familiar with them.

In the following settings a, b and c stand for any numbers whatsoever, while x represents the required quantity. Careful attention must be paid to the digits in the numbers of which roots are found. The decimal point may be located in each problem by properly combining the preceding rules, or by inspection in most cases.

SETTINGS FOR ONE AND TWO NUMBERS.

1. $x = 1 \div a^2$—Set 1 on C to a on D; at 1 on A read x on B.
2. $x = 1 \div \sqrt{a}$—Set 1 on B to a on A; at 1 on D read x on C.
3. $x = a^2 \times b$—Set 1 on C to a on D; at b on B read x on A.
4. $x = a^2 \div b$—Set b on B over a on D; at 1 on B read x on A.
5. $x = a \div b^2$—Set b on C under a on A; at 1 on B read x on A.
6. $x = a^2 \times b^2$—Set 1 on C to a on D; over b on C read x on A.
7. $x = a^2 \div b^2$—Set b on C to a on D; at 1 on B read x on A.
8. $x = a^3 \div b$—Set b on B to a on A; over a on C read x on A.
9. $x = a^3 \div b^2$—Set b on C to a on D; at a on B read x on A.
10. $x = a^4 \div b^2$—Set b on C to a on D; over a on C read x on A.
11. $x = \sqrt{a \times b}$—Set 1 on B to a on A; under b on B read x on D.
12. $x = \sqrt{a \div b}$—Set b on B to a on A; at 1 on C read x on D.

13. $x = a \times \sqrt{b}$—Set 1 on B to b on A; at a on C read x on D.
14. $x = a \div \sqrt{b}$—Set b on B over a on D; at 1 on C read x on D.
15. $x = \sqrt{a} \div b$—Set b on C under a on A; at 1 on C read x on D.
16. $x = \sqrt{a^3} \div b$—Set b on B to a on A; at a on C read x on D.
17. $x = \sqrt{a^3} \div b$—Set b on C to a on D; under a on B read x on D.

SETTINGS FOR THREE NUMBERS.

18. $x = a^2 \times b \div c$—Set c on B to b on A; over a on C read x on A.
19. $x = a^2 \times b \div c^2$—Set c on C to a on D; at b on B read x on A.
20. $x = a^2 \times b^2 \div c$—Set c on B over a on D; over b on C read x on A.
21. $x = a^2 \times b^2 \div c^2$—Set c on C to a on D; over b on C read x on A.
22. $x = \sqrt{a \times b \div c}$—Set c on B to a on A; under b on B read x on D.
23. $x = a \times \sqrt{b \div c}$—Set c on B to b on A; at a on C read x on D.
24. $x = \sqrt{a \times b} \div c$—Set c on C under a on A; under b on B read x on D.
25. $x = a \times b \div \sqrt{c}$—Set c on B over a on D; at b on C read x on D.
26. $x = \sqrt{a} \times b \div c$—Set c on C to b on D; under a on B read x on D.

XI. SCALE OF SINES.

63. **NOTATION OF SCALE.**—On the back of the slide are three scales each extending the full graduated length. Two of these are trigonometrical scales and the other is the scale of logarithms. The scale of sines is arranged above the other two and is marked for identification by the letter S. This scale is graduated from approximately 0° 35′ to 90°, as shown in Table IV.

TABLE IV.

	35′ TO 10°	10° TO 20°	20° TO 40°	40° TO 70°	70° TO 80°	80° TO 90°
Number of divisions.....	113	60	20	30	5	2
Value of each division....	5′	10′	30′	1°	2°	5°

64. **NATURAL SINES.**—If the slide be turned over so that the sine scale is adjacent to scale A of the rule, then with corresponding indices in line any angle on S is in contact with its natural sine on A. The maximum value of the sine is 1, the sines read on A′ having —1 digit, while those on A″ have zero digits. Thus sine 3° 35′ is .0625, and sine 20° 30′ is .350.

The sines of all angles may also be found with the slide in its normal position by setting the angle to the upper index mark in the right-hand recess in the base of the rule. The sine is then read under either index of A″, and the decimal point is located by remembering that angles between 35′ and 5° 44′ have —1 digit, and those between 5° 45′ and 90° have zero digits. Sines of angles greater than 90° may be determined from the following:

From 90° to 180°, sine a° = sine (180°—a°).
From 180° to 270°, sine a° = — sine (a°—180°).
From 270° to 360°, sine a° = — sine (360°—a°).

65. **SINES OF ANGLES 40° TO 90°.**—It will be seen that the divisions rapidly diminish in length, making it impossible to obtain accurate readings toward the end of the scale. Hence in most cases it is desirable to calculate the sines of angles between 40° and 90° using the relation

$$\text{Sine a}^\circ = 1 - 2 \times \text{sine}^2 \frac{90^\circ - \text{a}^\circ}{2}$$

The angle $\frac{90^\circ - \text{a}^\circ}{2}$ is set to the index of the recess and on B under the index of A″ is read the corresponding sine, or x, which is squared without shifting the slide by reading on B under x on A. This final value on B is then doubled and subtracted from 1.

As an example determine sine 78° 14′. Set $\frac{90^\circ - 78^\circ\ 14'}{2}$ or 5° 53′ to the upper index of the right-hand recess and under either index of A″ read .1025 on B, which squared gives .0105 on B′ under .1025 on A″. Hence sine 78° 14′ = 1 — 2 × .0105 or .979.

66. **SINES OF SMALL ANGLES.**—The sines of angles less than 35′ are almost exactly proportional to the corresponding angles, so that all such sines may be read directly. For this purpose there is a graduation on the sine scale designated (″) and another one marked (′). For sines of small angles expressed in seconds, the graduation (″) is placed in contact with the number on A which is numerically equal to the given angle, and then over the index of S is read its sine. For small angles expressed in minutes the graduation (′) is used in the same way. In locating the decimal points of these small angles, it must be noted that the sine of angles less than 2″ has — 5 digits; sine 3″ to sine 20″ has — 4 digits; sine 21″ to sine 3′ 26″ has — 3 digits; and sine 3′ 27″ to sine 34′ 23″ has — 2 digits.

67. **MULTIPLICATION AND DIVISION OF SINES.**—The

sines of angles may be multiplied or divided by the ordinary method for numbers, having scale S in contact with A.

TO MULTIPLY BY SINE.		
A	to number	read product
S	Set index	At angle

TO DIVIDE BY SINE.		
A	to number	read quotient
S	Set angle	At index

To divide the sine of an angle by any number, proceed as if dividing the number by the sine, but then read the number on B at the index of the recess, which will be the desired quotient. The decimal points in these problems are best located by inspection.

68. **NATURAL COSINES.**—The cosine of any angle a° is equal to sine (90° — a°). Hence by setting on the sine scale for (90°— a°), cosine a° is determined directly; and it may be multiplied or divided by the ordinary methods for sines. For accurately finding the cosines of angles less than 50° it is usually desirable to employ the following relation:

$$\text{Cosine } a° = 1 - 2 \times \sin^2 \frac{a°}{2}.$$

The cosines of angles between 89° 25′ and 90° may be found by means of the special graduations (″) and (′) on scale S, as shown in paragraph 66 for the determination of sines of very small angles.

Cosines of angles less than 84° 15′ have zero digits, while for angles between 84° 16′ and 89° 25′ there is one zero directly following the decimal point. The cosines of angles greater than 90° may be determined by means of the following:

From 90° to 180°, cosine a° = — sine (a°— 90°).
From 180° to 270°, cosine a° = — sine (270°— a°).
From 270° to 360°, cosine a° = sine (a°— 270°)

69. **NATURAL SECANTS.**—The secant of any angle is equal to the reciprocal of the cosine. Hence for any angle a°, (90° — a°) on S is set to the index of the recess and over 1 on B is read secant a° on A; or with (90°— a°) on S set to 1 on A, secant a° is read on A over the index of S. Rules may be stated for the position of the decimal point, but it is advisable to locate it by inspection.

70. **NATURAL COSECANTS.**—The cosecant of an angle is equal to the reciprocal of the sine of that angle, which may be found directly over the index of B with the angle set to the index of the recess. If scale S is placed in contact with A, then the angle on S is set to the index of A and at the index of S is read the cosecant on A. The decimal point is best located by inspection, remembering the rules for decimals in sines.

71. **NATURAL VERSED SINES AND COVERSED SINES.** —The versed sine of a° equals (1— cosine a°). while the co-

versed sine of a° is equal to (1— sine a°). These functions are found by obtaining the cosine and sine respectively, and subtracting the results from 1.

XII. SCALE OF TANGENTS.

72. **NOTATION OF SCALE.**—Along the lower edge of the under side of the slide is a scale of tangents marked T. It is used in conjunction with the lower scales, and with them gives directly the natural tangents of all angles from approximately 5° 43′ to 45°. From 5° 45′ to 20° there is a total of 171 divisions, each having a value of 5′, and from 20° to 45° there are 150 divisions, each being equivalent to 10′.

73. **NATURAL TANGENTS.**—By placing scale T adjacent to D of the rule and setting corresponding indices in line, the natural tangent of any angle on T is found in contact on D. Tangents may also be read with the slide in its normal position by setting the angle on T to the lower index of the left-hand recess of the rule and reading on C at the index of D. Thus the tangent of 13° 30′ is .24, the result always having zero digits for angles between 5° 43′ and 45°. Tangents of angles greater than 90° may be determined by aid of the following:

From 90° to 180°, tangent a° = — tangent (180°— a°).
From 180° to 270°, tangent a° = tangent (a°— 180°).
From 270° to 360°, tangent a° = — tangent (360°—a°).

The tangents of angles less than 5° 43′ are very closely equal to the corresponding sines, and hence may be determined directly from scale S. For very small angles expressed in seconds or minutes, the special graduations (″) or (′) respectively, on scale S give accurate results for tangents also.

74. **TANGENTS OF ANGLES 45° TO 90°.**—For these angles the natural tangents may be obtained by means of the relation

$$\text{Tangent } a° = \frac{1}{\text{tangent } (90° - a°)}$$

This operation is performed in one setting by placing (90°— a°) on T to 1 on D and at the index of T reading tangent a° on D. Tangents of angles between 45° and 84° 17′ have 1 digit; between 84° 18′ and 89° 25′, 2 digits; and at 90° the tangent is infinite.

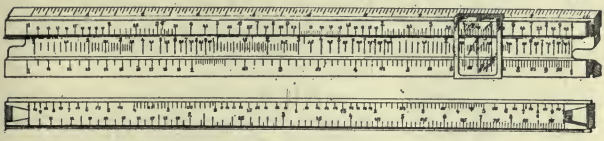
75. **MULTIPLICATION AND DIVISION OF TANGENTS.**—Problems of this kind are solved by the ordinary methods of multiplication and division as explained for natural sines in paragraph 67.

76. **NATURAL COTANGENTS.**—The cotangent of an angle equals the reciprocal of the corresponding tangent. With the

PART II.

THE MULTIPLEX SLIDE RULE

Part II—Multiplex Slide Rule



I. INTRODUCTION.

1. **APPLICATION.**—As its name implies, the Multiplex slide rule is a calculating instrument of many uses. Not only does it broaden the field of application, but it also offers a convenient means of more rapid working, securing greater accuracy at the same time. The theoretical and mechanical principles upon which the Multiplex slide rule is based, are identical in all respects to those underlying the action of the ordinary Mannheim rules, so that the operator has but little more to learn, although there is much to be gained.

Not only does the Multiplex solve all the arithmetical, trigonometrical and logarithmic examples which are possible with the Mannheim, and in the same convenient and rapid manner, but it further possesses the following characteristic advantages:

1. Multiplication of three numbers in one setting.
2. Division of one number by two numbers in one setting.
3. More convenient solution of inverse proportion.
4. Direct solution in a single setting of a series of divisions with a constant dividend.
5. Direct reading of cubes and cube roots.
6. Direct reading of three-halves and two-thirds powers.
7. Direct solution in a single setting of many combined operations which require the slide to be shifted with the Mannheim rule.

2. **ACCURACY.**—The division of all scales of our rules are practically perfect, so that the only errors which enter into the results of calculations are those due to setting and reading. Hence by reducing the number of times that the slide must be set and the scales read, the result of any calculation becomes more accurate, even where shorter scales are employed.

3. **SAVING IN TIME.**—Next to accuracy of results the calculator is most concerned with rapidity in working. Here again the Multiplex rule is superior to all others, since it eliminates some of the settings and readings required in many of the common problems.

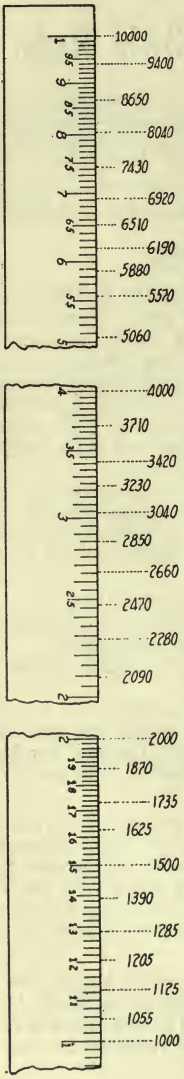


FIG. 1. READINGS ON SCALE B1 OF A TEN-INCH SLIDE RULE.

4. **MECHANICAL ADVANTAGES.**—Due to improved design the Multiplex is the most perfect acting and most durable of all types of slide rules. A study of the following text will reveal to the reader a simple instrument, of wide application, capable of rapid and accurate results, and one of superior and lasting mechanical qualities.

5. **NOTE.**—All processes of multiplication, division, proportion, powers, roots and logarithms, together with the determination of trigonometrical functions and combined operations, may be solved with the Multiplex just as with the Mannheim. Hence in the following text only those settings which are applicable to the Multiplex alone will be considered, the other features and principles common to both types of rules being understood from Part I.

II. CONSTRUCTION.

6. **GENERAL.**—The mechanical construction of the Multiplex is in general similar to that of the Mannheim, there being the same arrangement of body, slide and runner. We now manufacture three sizes of each of two forms of the Multiplex, one form having a reciprocal scale but no cube scale, while the other has both of these features. In the latter type the cube scale is located on the base between the two fixed rules, thus occupying the space beneath the slide, which in other types of rules is devoted to no useful purpose. The addition of the cube scale and the substitution of the reciprocal scale for B′ are the only differences between the scales of the Multiplex and the Mannheim slide rules. The scales of sines, tangents and logarithms are identical in arrangement and use for both types.

7. **SLIDE.**—For that form of the Multiplex rule which includes the cube scale, the slide has a recess provided at each end through which readings are

made on the cube scale. Each recess is spanned by a strip of metal, thus strengthening the mechanical construction and at the same time providing a convenient means for drawing out the slide.

8. **RECIPROCAL SCALE.**—Along the left-hand side of the upper edge of the slide there is a complete logarithmic scale progressing in the reversed direction, from the center index of B toward the left. This scale will be called the reciprocal scale of B or Br. It is exactly one-half the length of C or D, and hence equal to that of A′, A″ or B″. Scale Br and B″ are also identical in every other respect except that they progress in opposite directions from the center index of B. In order to avoid any possible confusion, the numbers on scale Br are colored red. In this way the attention of the operator is immediately drawn to the fact that the scale in question progresses in the reversed direction, from right to left.

9. **CUBE SCALE.**—This scale is located on the base between the fixed rules and underneath the slide. It is composed of three identical and complete logarithmic scales, E′, E″ and E‴, progressing from left to right, and each being exactly one-third the length of C or D and two-thirds that of any one of the upper scales. The outer indices of E are accurately in line with those of the fixed rules, while the indicator lines (I. L.) of the cube scale are carried in the recesses of the slide directly in line with the corresponding indices of scales B and C.

10. **READING SCALE Br.**—The division of the reciprocal scale is identical with that of the other upper scales, as shown in Table I for its right-hand index equal to 1.

TABLE I.

	FIVE AND TEN-INCH RULES.			TWENTY-INCH RULE		
	10 TO 5	5 TO 2	2 TO 1	10 TO 4	4 TO 2	2 TO 1
Value of each main division	1.00	1.00	1.00	1.00	1.00	1.00
Value of each minor division	...	.10	.10	.10	.10	.10
Value of smallest division	.10	.05	.02	.05	.02	01
Total number of divisions	50	60	50	120	100	100

A little practice will accustom the reader to accurately and quickly read the reversed graduations and to readily pass from this scale to others progressing in the opposite direction. Fig. 1 (see page 38) should be carefully examined and compared with the ten-inch rule, and then the following settings and readings should be performed with the reciprocal scale. Set 3 on Br to 4 on A′ and at 1 on Br read 12 on A; note that 3 on A′ and 4 on Br are likewise in contact, and that 12 on Br is at the center index of A. Set 125 on Br to 36 on A′ and at 1 on Br read 4500 on A′. Set 1 on Br to 884 on A″ and at 425 on Br read 2.08 on A″.

11. **READING SCALE E.**—Scale E consists of the three parts E′, E″ and E‴, the first being taken on the extreme left and E‴ on the extreme right. Each of these scales progresses from left to right and is divided in exactly the same way as the upper scales of the slide and rule.

III. MULTIPLICATION.

12. **MECHANICAL PRINCIPLES.**—By drawing two linear scales with equal divisions throughout, but progressing in opposite directions, the addition of any number of units on one with those on the other may be obtained mechanically by setting the two quantities together, as shown in Fig. 2. With 0

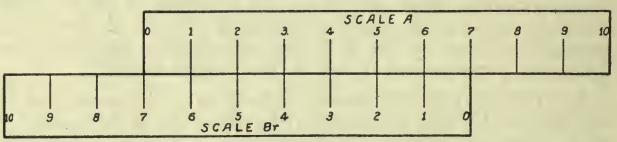


FIG. 2. ADDITION AND SUBTRACTION WITH REVERSED SCALE.

on Br set to 7 on A, it will be observed that any two numbers on the scales whose sum is 7 are in contact.

13. **TWO FACTORS.**—From the simple principle of the preceding paragraph it will be evident that by setting the logarithm of any number on Br to the logarithm of any number on A, their sum, which is the logarithm of the corresponding product, is found on A at the index of Br. In the manner shown in the tabular statement below, the logarithms are added exactly as with scales progressing in the same direction.

A	to second number	read product
Br	Set one number	At 1

14. **THREE FACTORS.**—One of the many useful advantages of the Multiplex rule is multiplication of three numbers with but one setting of the slide. It will be observed that the product of two factors, using scale Br, is found on A at the index of Br, which is then the required setting for the multiplication of that product by any third factor on B″ within the range of contact.

A′	to second number	A	read final product
Br	Set one number	B″	At third number

The first and second factors are always taken on Br and A′, from which it will be observed that the logarithms of the three numbers are directly added in all cases.

15. **CONSTANT PRODUCT.**—If the index of Br or B″ be set to a given number on A, all combinations of two factors whose products equal the given number will be found in contact between Br and A. Similarly if the product of three fac-

tors is to be a constant quantity, then all sets of its factors may be determined by setting the runner to the given quantity on A″ and bringing any number on B″ to the hair-line, when the other two corresponding factors will be in contact on Br and A. These principles are of much importance in engineering design work and are characteristic features of the Multiplex slide rule.

16. **PROPORTION.**—Direct proportion is best solved with the scales C and D or A and B″. Inverse proportion is most conveniently performed by means of the reciprocal scale of the Multiplex rule, the method being similar to that for the Mannheim rule with its slide inverted. As an example, assume that the electrical resistance of 1000 feet of copper wire having a cross-section of 350,000 circular mils in .030 ohm. What is the resistance of 1000 feet of copper wire of 700,000 circular mils section?

A	to .030 ohms	read .015 ohms
Br	Set 350,000 circular mils	At 700,000 circular mils

By this method the problem is solved as if dealing with direct proportion on the other scales.

17. **DECIMAL POINT.**—The rules for locating the decimal point in a product obtained by using the reciprocal scale are simple and may be remembered as follows:

If the first significant figure of the product of two numbers is greater than the first significant figures of both factors, then the number of digits in the product is one less than the sum of the digits in the two factors; if less, the digits in the product is simply equal to their sum. Where the first significant figures are the same, the following figures must be likewise compared.

The number of digits in the product of three factors obtained in one setting is two less than the sum of those in the three factors if the final product is read on A′, and is one less than their sum if read on A″.

In multiplying more than three factors together the above rules are combined for the digits in the product, or the decimal point is located by inspection.

18. **EXAMPLES.**—The reader should work the following examples using scale Br and then compare the operation in each case with the process required for the lower scales:

EXAMPLE	SUM OF DIGITS	FINAL PRODUCT READ ON SCALE	DIGITS IN PRODUCT	ANSWER
$24 \times 1.42 \times 18.2$	5	A′	3	620
$182 \times 2.95 \times .087$	3	A″	2	46.7
$.0024 \times .56 \times 7.1$	−1	A″	−2	.00954

IV. DIVISION.

19. **MECHANICAL PRINCIPLES.**—Using linear scales progressing in opposite directions, any number may be subtracted from another by setting one index to the latter number on the other scale, and reading at the number to be subtracted. In Fig. 2 (see page 40) the index of Br is set to 7 on A, and at 2 on Br is 5 on A; and similarly for 1 and 6, 3 and 4, etc. In the same way any two logarithms on the slide rule may be subtracted, giving the logarithm of the quotient of the corresponding numbers. Hence for division,

A	to dividend	read quotient	Br
Br	Set 1	At divisor	A

20. **CONSTANT DIVIDEND.**—If a constant quantity is to be divided by a series of numbers the entire set of quotients may be read off directly without shifting the slide. The index of B is set to the constant dividend on A and at the divisors on Br are read in turn the corresponding quotients on A.

21. **RECIPROCALS.**—The reciprocals of all numbers may be read directly on the Multiplex rule without shifting the slide. For this operation the index on Br is set to the index on A and at any number on Br is read its reciprocal on A, or vice versa.

22. **CONTINUED DIVISION.**—Any number may be divided by two numbers in one setting of the Multiplex rule. One divisor on B″ is set to the dividend on A″ and at the other divisor on Br is read the final quotient on A.

A″	to dividend	A	read final quotient
B″	Set one divisor	Br	At other divisor

By this method the sum of the logarithms of the two divisors is directly subtracted from the logarithm of the dividend.

23. **DECIMAL POINT.**—The number of digits in a quotient may be determined as follows:

If the first significant figure of the divisor is greater than that of the dividend, the number of digits in the quotient of the two numbers is equal to the digits in the dividend less those in the divisor; if less, then one digit must be added to this difference. The following significant figures are to be compared where the first ones are alike.

Where one number is divided by two divisors, the number of digits in the final quotient is two more than the difference between the digits of the dividend and divisors if the final quotient is read on A″, and one more than their difference if read on A′.

24. **EXAMPLES.**—The reader should solve the following problems using scale Br, and then compare this method with the operations required for the lower scales:

DIVIDEND	FIRST DIVISOR	SECOND DIVISOR	DIFFERENCE OF DIGITS	FINAL QUOTIENT READ ON SCALE	DIGITS IN FINAL QUOTIENT	ANSWER
985	.023	168	1	A″	3	255
.0046	.325	.199	−2	A′	−1	.0712
6200	8.4	3.95	2	A′	3	187

V. POWERS AND ROOTS.

25. **GENERAL.**—Since the scales A′, A″, B″, C and D of the two types of rules are identical, all problems and settings involving them may be performed in exactly the same way. Hence almost all the cases given in Chapter VIII of Part I covering powers and roots apply equally well to the Multiplex rule. However, the following solutions are best determined with the Multiplex and will be found of much value to the calculator.

26. **SOLUTION OF $\frac{1}{a^2}$.**—Problems of this form may be solved directly by setting the reciprocal scale over a on D, having the proper indices of Br and A in line, and then reading on Br above a on D. For numbers less than 3162.... $\frac{1}{a^2}$ may be read on Br directly above a on C. The decimal point in such problems is best located by inspection.

27. **SOLUTION OF $\frac{1}{\sqrt{a}}$.**—Much saving in time may be effected in a series of problems of this kind by using the Multiplex rule. For numbers having odd digits, the left index of Br is set to the center index of A and under a on Br is read $\frac{1}{\sqrt{a}}$ on D. For numbers having even digits, $\frac{1}{\sqrt{a}}$ may be found on C directly under a on Br.

28. **CUBES.**—Since scale D is three times the length of each of the scales comprising E, the logarithm of any number on D is directly in line with three times that logarithm on E. Hence any number on D is in line with its cube or third power on E.

E		At I. L. on slide read cube of number
C	Set 1	
D	to number	

If read on E′, the cube has two less than three times the digits in the given number; if read on E″, it has one digit less;

and where read on E‴, the digits in the cube simply equal three times the digits of the given number. Hence the cube of .16 is .0041; $\overline{42}^3 = 74{,}100$; and $\overline{76}^3 = 439{,}000$.

29. **CUBE ROOTS.**—The cube root of a number, which is the same as its one-third power, may be read directly by referring from E to D as follows:

E	Set I. L. on slide to number	
C		At 1
D		read cube root of number

There are three cube roots of any string of figures, the proper one for any given number depending on its digits. For numbers containing — 8, — 5, — 2, 1, 4, 7, etc., digits, scale E′ is used; for numbers of — 7, — 4, — 1, 2, 5, 8, etc., digits, scale E″ is used; and for numbers having — 6, — 3, 0, 3, 6, 9, etc., digits, the given number is taken on E‴. There is one digit in the cube root for each period of three figures, or less in the extreme period, contained in the given number, counting from the decimal point toward the left for numbers greater than 1, and toward the right for decimals. The periods in decimals indicate minus digits. With these principles in mind the cube root of 9 is seen to be 2.08; $\sqrt[3]{43{,}000} = 35$; $\sqrt[3]{.000{,}125} = .05$.

30. **THREE-HALVES POWERS.**—Since the length of scale A′ or A″ is exactly three-halves times that of either E′, E″ or E‴, the three-halves power of any number may be determined directly with the Multiplex rule by passing from A to E.

A	to number	
B	Set 1	
E		At I. L. on slide read three-halves power of number

In this process numbers having odd digits are taken on A′, while those with even digits are taken on A″.

The decimal point in the three-halves power may be located by the following. Representing the number of digits in the given number by Nn and those in the power by Np,

For power on E′, $Np = \left(Nn \times \frac{3}{2}\right) - \frac{1}{2}$.

For power on E″ and number on A′, $Np = \left(Nn \times \frac{3}{2}\right) + \frac{1}{2}$.

For power on E″, and number on A″, $Np = \left(Nn \times \frac{3}{2}\right) - 1$

For power on E‴, $Np = Nn \times \frac{3}{2}$.

As examples, the three-halves power of 4 is 8; $(933)^{3/2} = 28{,}500$; $\sqrt{\overline{.0015}^3} = .000{,}058$; and $\sqrt{\overline{66}^3} = 536$.

31. **TWO-THIRDS POWERS.**—This operation is the reverse of the preceding, as shown below:

A		read two-thirds power of number
B		At 1
E	Set I.L. on slide to number	

Numbers having $-8, -5, -2, 1, 4, 7$, etc., digits, are taken on E′; for $-7, -4, -1, 2, 5, 8$, etc. digits, use scale E″; and for $-6, -3, 0, 3, 6, 9$, etc., digits, the number is taken on E‴.

By referring to paragraph 29 it will be seen that the proper scale of E to use in finding the two-thirds power of a given number is the same as for its cube root. Hence both the one-third and two-thirds powers of any number may be determined from the same setting; and similarly for the second and third powers, and for the one-half and three-halves powers.

The number of digits in the two-thirds power may be found as follows, wherein the same notation is used as in the preceding paragraph:

For number on E′, $Np = \left(Nn \times \frac{2}{3}\right) + \frac{1}{3}$.

For number on E″ and power on A′, $Np = \left(Nn \times \frac{2}{3}\right) - \frac{1}{3}$.

For number on E″ and power on A″, $Np = \left(Nn \times \frac{2}{3}\right) + \frac{2}{3}$.

For number on E‴, $Np = Nn \times \frac{2}{3}$.

32. **OTHER POWERS AND ROOTS.**—By properly combining the scales of the Multiplex and using the runner for intermediate results, a great variety of powers and roots may be readily determined. For a series of examples involving the same process such methods are recommended, but for a single problem it is sometimes better to resort to the scale of logarithms on the back of the slide, using the method outlined in Chapter XIII of Part I.

VI. SETTINGS FOR THE MULTIPLEX SLIDE RULE.

33. **LIST OF SETTINGS.**—The following settings are intended to supplement those of Chapter X Part I, all of the latter being applicable to the Multiplex rule also. The additional value of the Multiplex slide rule may be judged from the great variety of important operations which may be solved in a single setting. By using the runner for intermediate results and settings, the list may be enlarged to an almost unlimited extent.

The operator must pay attention to the digits in the given number and the intermediate results, in order to determine which part of the upper and cube scales to use in any case, The decimal point in the final result is usually best determined by inspection, although the preceding rules for digits may be combined for the purpose.

The letters a, b and c represent any numbers whatsoever, while x is used for the required result. It will be remembered that I. L. stands for the indicator line of the cube scale, while CI, B″I and BrI designate scales C, B″ and Br respectively, with the slide inverted.

SETTINGS FOR ONE NUMBER.

1. $x = a^2$—Set 1 on C to a on D; at 1 on B read x on A.
2. $x = a^3$—Set 1 on C to a on D; at I. L. read x on E.
3. $x = a^4$—Set 1 on C to a on D; over a on C read x on A.
4. $x = a^5$—Set a on CI over a on D; over a on BrI read x on A.
5. $x = a^6$—Set a on CI over a on D; at I. L. read x on E.
6. $x = 1 \div a^2$—Set 1 on B to 1 on A; over a on D read x on Br.
7. $x = 1 \div a^3$—Set a on Br over a on D; at 1 on A read x on B″.
8. $x = 1 \div a^4$—Set a on CI over a on D; at 1 on D read x on BrI.
9. $x = \sqrt{a}$—Set 1 on B to a on A; at 1 on C read x on D.
10. $x = \sqrt{a^3}$—Set 1 on B to a on A; at I. L. read x on E.
11. $x = \sqrt{a^5}$—Set a on CI over a on D; at a on BrI read x on D.
12. $x = \sqrt{a^9}$—Set a on Br over a on D; at I. L. read x on E.
13. $x = \sqrt[3]{a}$—Set I. L. to a on E; at 1 on C read x on D.
14. $x = \sqrt[3]{a^2}$—Set I. L. to a on E; at 1 on B read x on A.
15. $x = \sqrt[3]{a^4}$—Set I. L. to a on E; at a on C read x on D.
16. $x = \sqrt[3]{a^5}$—Set I. L. to a on E; at a on B″ read x on A.
17. $x = \sqrt[3]{a^8}$—Set I. L. to a on E; over a on C read x on A.
18. $x = \sqrt[6]{a^5}$—Set I. L. to a on E; under a on B″ read x on D.
19. $x = 1 \div \sqrt[3]{a}$—Set I. L. to a on E; at 1 on D read x on C.
20. $x = 1 \div \sqrt[3]{a^2}$—Set I. L. to a on E; at 1 on A read x on B″.
21. $x = 1 \div \sqrt[3]{a^4}$—Set I. L. to a on E; at a on CI read x on A.
22. $x = 1 \div \sqrt[6]{a}$—Set I. L. to a on E; under a on Br read x on D.

SETTINGS FOR TWO NUMBERS.

23. $x = a \times b$—Set a on Br to b on A; at 1 on B read x on A.
24. $x = a \div b$—Set 1 on B to a on A; at b on Br read x on A.
25. $x = a \times b^2$—Set 1 on B to a on A; over b on C read x on A.
26. $x = a \div b^2$—Set b on C under a on A; at 1 on B read x on A.
27. $x = a^2 \div b$—Set 1 on C to a on D; at b on Br read x on A.
28. $x = a^2 \times b^2$—Set 1 on C to a on D; over b on C read x on A.
29. $x = a^2 \div b^2$—Set b on C to a on D; at 1 on B read x on A.
30. $x = a^3 \times b$—Set a on B″I to a on D; over b on BrI read x on A.
31. $x = a^3 \div b$—Set a on B″I to a on D; over b on B″I read x on A.
32. $x = a \div b^3$—Set b on C under a on A″; at b on Br read x on A.

33. $x = a^3 \times b^2$—Set a on CI over b on D; over a on BrI read x on A.
34. $x = a^3 \div b^2$—Set b on C to a on D; at a on B″ read x on A.
35. $x = a^2 \div b^3$—Set b on C to a on D; at b on Br read x on A.
36. $x = a^3 \times b^3$—Set a on CI over b on D; at I. L. read x on E.
37. $x = a^3 \div b^3$—Set b on C to a on D; at I. L. read x on E.
38. $x = a^4 \times b$—Set a on CI over a on D; over b on BrI read x on A.
39. $x = a^4 \div b$—Set a on CI over a on D; over b on B″I read x on A.
40. $x = a \div b^4$—Set b on CI over b on D; under a on A read x on BrI.
41. $x = a^4 \div b^2$—Set b on C to a on D; over a on C read x on A.
42. $x = 1 \div (a \times b)$—Set a on Br to b on A; at 1 on A read x on B″.
43. $1 \div (a^2 \times b)$—Set b on Br over a on D; at 1 on A read x on B″.
44. $x = 1 \div (a^2 \times b^2)$—Set a on CI over b on D; at 1 on D read x on BrI.
45. $x = \sqrt{a \times b}$—Set a on Br to b on A; at 1 on C read x on D.
46. $x = \sqrt{a \div b}$—Set b on B″ to a on A; at 1 on C read x on D.
47. $x = a \times \sqrt{b}$—Set 1 on C to a on D; under b on B″ read x on D.
48. $x = a \div \sqrt{b}$—Set b on B″ over a on D; at 1 on C read x on D.
49. $x = \sqrt{a} \div b$—Set b on C under a on A; at 1 on C read x on D.
50. $x = a \times \sqrt{b^3}$—Set b on Br over a on E; at I. L. read x on E.
51. $x = a \div \sqrt{b^3}$—Set b on B″ over a on E; at I. L. read x on E.
52. $x = a^3 \times \sqrt{b^3}$—Set b on Br over a on D; at I. L. read x on E.
53. $x = a^3 \div \sqrt{b^3}$—Set b on B″ over a on D; at I. L. read x on E.
54. $x = \sqrt{a^3} \div b^3$—Set b on C under a on A; at I. L. read x on E.
55. $x = \sqrt{a^3 \times b^3}$—Set a on Br to b on A; at I. L. read x on E.
56. $x = \sqrt{a^3 \div b^3}$—Set b on B″ to a on A; at I. L. read x on E.
57. $x = a \times \sqrt[3]{b}$—Set I. L. to b on E; at a on C read x on D.
58. $x = a \div \sqrt[3]{b}$—Set a on C over b on E; at 1 on D read x on C.
59. $x = \sqrt[3]{a} \div b$—Set I. L. to a on E; under b on CI read x on D.
60. $x = a \times \sqrt[3]{b^2}$—Set I. L. to b on E; at a on B″ read x on A.
61. $x = \sqrt[3]{a^2} \div b$—Set I. L. to a on E; at b on Br read x on A.
62. $x = a \div \sqrt[3]{b^2}$—Set a on B″ over b on E; at 1 on A read x on B″.
63. $x = a^2 \times \sqrt[3]{b^2}$—Set I. L. to b on E; over a on C read x on A.
64. $x = \sqrt[3]{a^2} \div b^2$—Set I. L. to a on E; at b on CI read x on A.
65. $x = a^2 \div \sqrt[3]{b^2}$—Set a on C over b on E; at 1 on A read x on B″.
66. $x = 1 \div \sqrt{a \times b}$—Set a on Br to b on A; at 1 on D read x on C.
67. $x = 1 \div (a \times \sqrt{b})$—Set a on C to 1 on D; under b on Br read x on D.

SETTINGS FOR THREE NUMBERS.

68. $x = a \times b \times c$—Set a on Br to b on A′; at c on B″ read x on A.
69. $x = a \times b \div c$—Set a on Br to b on A; at c on Br read x on A.
70. $x = a \div (b \times c)$—Set b on B″ to a on A″; at c on Br read x on A.
71. $x = a \times b \times c^2$—Set a on Br to b on A; over c on C read x on A.
72. $x = a^2 \times b \div c$—Set b on Br over a on D; at c on Br read x on A.
73. $x = a \times b \div c^2$—Set c on C under a on A; at b on B″ read x on A.
74. $x = a^2 \div (b \times c)$—Set b on B″ over a on D; at c on Br read x on A.
75. $x = a^2 \times b^2 \div c$—Set c on B″ over a on D; over b on C read x on A.
76. $x = a^2 \times b \div c^2$—Set c on C to a on D; at b on B″ read x on A.
77. $x = a^2 \times b^2 \div c^2$—Set c on C to a on D; over b on C read x on A.
78. $x = a^3 \times b^3 \div c^3$—Set c on C to a on D; under b on C read x on E.
79. $x = \sqrt{a \times b \times c}$—Set a on Br to b on A′; under c on B″ read x on D.
80. $x = \sqrt{a \times b \div c}$—Set a on Br to b on A; under c on Br read x on D.
81. $x = \sqrt{a \div (b \times c)}$—Set b on B″ to a on A″; under c on Br read x on D.
82. $x = a \times \sqrt{b \times c}$—Set b on Br to c on A; at a on C read x on D.
83. $x = \sqrt{a \times b} \div c$—Set c on C under a on A; under b on B″ read x on D.
84. $x = a \times b \times \sqrt{c}$—Set c on Br over a on D; at b on C read x on D.
85. $x = \sqrt{a} \times b \div c$—Set c on C to b on D; under a on B″ read x on D.
86. $x = \sqrt{a} \div (\sqrt{b} \times c)$—Set b on BrI under a on A; under c on CI read x on D.
87. $x = \sqrt{a^3 \times b^3 \div c^3}$—Set a on Br to b on A′; under c on B″ read x on E.
88. $x = \sqrt{a^3 \div (b^3 \times c^3)}$—Set b on B″ to a on A″; under b on Br read x on E.
89. $x = \sqrt{a^3 \times b^3} \div c^3$—Set c on C under a on A; under b on B″ read x on E.
90. $x = a^3 \times \sqrt{b^3 \div c^3}$—Set c on B″ to b on A; under a on C read x on E.
91. $x = a^3 \times b^3 \times \sqrt{c^3}$—Set a on CI over b on D; under c on BrI read x on E.
92. $x = a^3 \times \sqrt{b^3} \div c^3$—Set c on C to a on D; under b on B″ read x on E.
93. $x = a^3 \times b^3 \div \sqrt{c^3}$—Set c on B″ over a on D; under b on C read x on E.

PART III.

CONVERSION RATIOS

Part III—Conversion Ratios

I. DECIMAL EQUIVALENTS OF FRACTIONAL PARTS.

FRACTION	$\frac{1}{32}$S	$\frac{1}{64}$S	DECIMAL	FRACTION	$\frac{1}{32}$S	$\frac{1}{64}$S	DECIMAL
		1	.015625			33	.515625
	1	2	.03125		17	34	.53125
		3	.046875			35	.546875
$\frac{1}{16}$	2	4	.0625	$\frac{9}{16}$	18	36	.5625
		5	.078125			37	.578125
	3	6	.09375		19	38	.59375
		7	.109375			39	.609375
$\frac{1}{8}$	4	8	.125	$\frac{5}{8}$	20	40	.625
		9	.140625			41	.640625
	5	10	.15625		21	42	.65625
		11	.171875			43	.671875
$\frac{3}{16}$	6	12	.1875	$\frac{11}{16}$	22	44	.6875
		13	.203125			45	.703125
	7	14	.21875		23	46	.71875
		15	.234375			47	.734375
$\frac{1}{4}$	8	16	.25	$\frac{3}{4}$	24	48	.75
		17	.265625			49	.765625
	9	18	.28125		25	50	.78125
		19	.296875			51	.796875
$\frac{5}{16}$	10	20	.3125	$\frac{13}{16}$	26	52	.8125
		21	.328125			53	.828125
	11	22	.34375		27	54	.84375
		23	.359375			55	.859375
$\frac{3}{8}$	12	24	.375	$\frac{7}{8}$	28	56	.875
		25	.390625			57	.890625
	13	26	.40625		29	58	.90625
		27	.421875			59	.921875
	14	28	.4375	$\frac{15}{16}$	30	60	.9375
$\frac{7}{16}$		29	.453125			61	.953125
	15	30	.46875		31	62	.96875
		31	.484375			63	.984375
$\frac{1}{2}$	16	32	.5	1	32	64	1.

II. METRIC SYSTEM OF UNITS.

MEASURES OF LENGTH, CAPACITY AND WEIGHT.

LENGTH

KILOMETER	HECTOMETER	DECAMETER	METER	DECIMETER	CENTIMETER	MILLIMETER
1	10	100	1,000	10,000	100,000	1,000,000
.1	1	10	100	1,000	10,000	100,000
.01	.1	1	10	100	1,000	10,000
.001	.01	.1	1	10	100	1,000
.000,1	.001	.01	.1	1	10	100
.000,01	.000,1	.001	.01	.1	1	10
.000,001	.000,01	.000,1	.001	.01	.1	1

CAPACITY

KILOLITER OR STERE	HECTOLITER OR DECISTERE	DECALITER OR CENTISTERE	LITER OR MILLISTERE	DECILITER	CENTILITER	MILLILITER

WEIGHT

KILOGRAM	HECTOGRAM	DECAGRAM	GRAM	DECIGRAM	CENTIGRAM	MILLIGRAM

1 Myriameter = 10 Kilometers = 10,000 Meters.

1 Metric Ton = 1,000 Kilograms = 100 Quintals = 10 Myriagrams.

1 Liter = 1 Cubic Decimeter.

SQUARE OR SURFACE MEASURE.

SQUARE KILOMETER	SQUARE HECTOMETER OR HECTARE	SQUARE DECAMETER OR ARE	SQUARE METER OR CENTIARE	SQUARE DECIMETER	SQUARE CENTIMETER	SQUARE MILLIMETER
1	100	10,000	1,000,000	.....	.....	.....
.01	1	100	10,000	1,000,000	.....	.....
.000,1	.01	1	100	10,000	1,000,000	.....
.000,001	.000,1	.01	1	100	10,000	1,000,000
.....	.000,001	.000,1	.01	1	100	10,000
.....	.....	.000,001	.000,1	.01	1	100
.....	.....	.....	.000,001	.000,1	.01	1

1 Square Myriameter = 100 Square Kilometers = 100,000,000 Square Meters.

CUBIC MEASURE.

CUBIC DECAMETER	CUBIC METER	CUBIC DECIMETER	CUBIC CENTIMETER	CUBIC MILLIMETER
1	1000	1,000,000	1,000,000,000	.....
.001	1	1,000	1,000,000	1,000,000,000
.000,001	.001	1	1,000	1,000,000
.000,000,001	.000,001	.001	1	1,000
.....	.000,000,001	.000,001	.001	1

1 Cubic Meter = 1 Kiloliter = 1 Stere.

III. SIMPLE EQUIVALENTS.

GEOMETRICAL RATIOS.

SCALE C	SCALE D	SCALE C	SCALE D	IF C=1, D=	IF D=1, C=
Diameter of Circle	Circumference of Circle	226	710	3.1416	.3183
Diameter of Circle	Side of Inscribed Square	99	70	.7071	1.4142
Diameter of Circle	Side of Equal Square	79	70	.8862	1.1284
Side of Square	Diagonal of Square	70	99	1.4142	.7071
Area of Circle	Area of Inscribed Square	300	191	.6366	1.5708
Area of Circle	Area of Circumscribed Square	62	79	1.2732	.7854

LINEAR MEASURE—(UNITED STATES AND BRITISH).

INCHES	FEET	YARDS	RODS	FURLONGS	MILES
1	.083,33	.027,78	.005,050,5	.000,126,26	.000,015,78
12	1.	.333,33	.060,606,1	.001,515,15	.000,189,39
36	3.	1.	.181,818,2	.004,545,45	.000,568,18
198	16.5	5.5	1.	.025	.003,125
7,920	660.	220.	40.	1.	.125
63,360	5,280.	1,760.	320.	8.	1.

ROPE AND CABLE MEASURE.

1 Inch = .111,111 Span = .013,889 Fathom = .000,115,7 Cable's Length.

1 Span = 9 Inches = .125 Fathom = .001,041,67 Cable's Length.

1 Fathom = 6 Feet = 8 Spans = 72 Inches = .008,333 Cable's Length.

1 Cable's Length = 120 Fathoms = 720 Feet = 960 Spans = 8,640 Inches.

GUNTER'S OR SURVEYOR'S CHAIN.

1 Link = 7.92 Inches = .01 Chain = .000,125 Mile.
1 Chain = 100 Links = 66 Feet = 4 Rods = .012,5 Mile.
1 Mile = 80 Chains = 8,000 Links.

RATIOS OF LENGTHS.

SCALE C	SCALE D	SCALE C	SCALE D	IF C=1, D=	IF D=1, C=
1–64 Inch	Millimeters	320	127	.3969	2.5197
Inches	Millimeters	5	127	25.400	.03937
Feet	Meters	82	25	.3048	3.2808
Yards	Meters	35	32	.9144	1.0936
Rods	Meters	37	186	5.0292	.1988
Chains (Surveyor's)	Meters	17	342	20.117	.0497
Miles	Kilometers	23	37	1.6094	.6214
Miles	Knots	38	33	.8684	1.1515

SQUARE OR LAND MEASURE—(UNITED STATES AND BRITISH).

SQUARE INCHES	SQUARE FEET	SQUARE YARDS
1	.006,944	.000,771,6
144	1.	.111,111
1,296	9.	1.
39,204	272.25	30.25
6,272,640	43,560.	4,840.
.....	27,878,400.	3,097,600.

SQUARE RODS	ACRES	SQUARE MILES
.....	.....	.....
.....	.....	.....
.033,06	.000,206,6	.....
1.	.006,25	.000,009,77
160.	1.	.001,562,5
102,400.	640.	1.

RATIOS OF AREAS.

SCALE C	SCALE D	SCALE C	SCALE D	IF C = 1, D =	IF D = 1, C =
Circular Mils...	Square Mils...	79	62	.7854	1.2732
Circular Inches	Square Centimeters.....	434	2200	5.0671	.1974
Square Inches	Square Centimeters.....	31	200	6.4516	.1550
Square Feet....	Square Meters	140	13	.0929	10.764
Square Yards..	Square Meters	61	51	.8361	1.1960
Square Miles	Square Kilometers.....	56	145	2.590	.3861
Acres.....	Hectares.....	42	17	.4047	2.471

CUBIC OR SOLID MEASURE—(UNITED STATES AND BRITISH).

1 Cubic Inch = .000,578,7 Cubic Foot = .000,021,433 Cubic Yard.

1 Cubic Foot = 1,728 Cubic Inches = .037,037,04 Cubic Yard.

1 Cubic Yard = 27 Cubic Feet = 46,656 Cubic Inches.

1 Cord of Wood = 128 Cubic Feet = 4 Feet by 4 Feet by 8 Feet.

DRY MEASURE—(UNITED STATES ONLY).

PINTS	QUARTS	GALLONS	PECKS	BUSHELS	CUBIC INCHES
1	.50	.125	.062,5	.015,625	33.600,312,5
2	1.	.25	.125	.031,25	67.200,625
8	4.	1.	.5	.125	268.802,5
16	8.	2.	1.	.25	537.605
64	32.	8.	4.	1.	2,150.42

LIQUID MEASURE—(UNITED STATES ONLY).

GILLS	PINTS	QUARTS	GALLONS	BARRELS	CUBIC INCHES
1	.25	.125	.031,25	.000,498	7.218,75
4	1.	.5	.125	.003,968	28.875
8	2.	1.	.25	.007,937	57.75
32	8.	4.	1.	.031,746	231.
2,008	252.	126.	31.5	1.	7,276.5

RATIOS OF CAPACITIES.

SCALE C	SCALE D	SCALE C	SCALE D	IF C=1, D=	IF D=1, C=
Cubic Inches	Cubic Centimeters	36	590	16.387	.0610
Cubic Feet	Cubic Meters	106	3	.0283	35.315
Cubic Feet	Bushels (U. S.)	61	49	.8036	1.2445
Cubic Yards	Cubic Meters	51	39	.7646	1.3079
Pints (U. S. Liquid)	Pints (U. S. Dry)	71	61	.8594	1.1637
Pints (U. S. Liquid)	Liters	93	44	.4732	2.1134
Pints (U. S. Dry)	Pints (British)	96	93	.9690	1.0320
Gallons (U. S. Liquid)	Liters	42	159	3.7854	.2642
Gallons (U. S. Liquid)	Imperial Gallons	6	5	.8327	1.2009

AVOIRDUPOIS WEIGHT—(UNITED STATES AND BRITISH.)

GRAINS	DRAMS	OUNCES
1.	.036,57	.002,286
27.343,75	1.	.062,5
437.5	16.	1.
7,000.	256.	16.
784,000.	28,672.	1,792.
5,680,000.	573,440.	35,840.

POUNDS	HUNDREDWEIGHTS	LONG OR GROSS TONS
.000,143	.000,001,28	.000,000,176
.003,906	.000,034,88	.000,001,744
.062,5	.000,558,04	.000,027,90
1.	.008,928,6	.000,446,4
112.	1.	.05
2,240.	20.	1.

1 Pound Avoirdupois = 1.215,278 Pounds Troy.

1 Net or Short Ton = 2,000 Pounds = .892,857 Long or Gross Ton.

TROY WEIGHT—(UNITED STATES AND BRITISH).

GRAINS	PENNYWEIGHTS	OUNCES	POUNDS
1	.041,667	.002,083,3	.000,173,6
24	1.	.05	.004,166,7
480	20.	1.	.083,333,3
5,760	240.	12.	1.

APOTHECARIES' WEIGHT—(UNITED STATES AND BRITISH).

GRAINS	SCRUPLES	DRAMS	OUNCES	POUNDS
1	.05	.016,667	.002,083,3	.000,173,611
20	1.	.333,333	.041,666,7	.003,472,2
60	3.	1.	.125	.010,416,7
480	24.	8.	1.	.083,333,3
5,760	288.	96.	12.	1.

The pound, ounce and grain are the same as in troy weight. The avoirdupois grain = troy grain = apothecaries' grain.

SCALE C	SCALE D	SCALE C	SCALE D	IF C = 1, D =	IF D = 1, C =
Grains	Grams	710	46	.0648	15.432
Ounces (Avoird.)	Grams	6	170	28.350	.0353
Ounces (Avoird.)	Ounces (Troy)	90	82	.9115	1.0971
Pounds (Avoird.)	Kilograms	97	44	.4536	2.2046
Tons (Short)	Tons (Long)	93	83	.8929	1.1200
Tons (Short)	Metric Tons	75	68	.9072	1.1023
Tons (Long)	Metric Tons	62	63	1.0161	.9842

ANGULAR OR CIRCULAR MEASURE.

SECONDS	MINUTES	DEGREES	RADIANS	QUADRANTS	CIRCUMFERENCES
1	.016,67	.000,278	.000,004,9	.000,003,1	.....
60	1	.016,67	.000,291	.000,185	.000,046,3
3,600	60	1.	.017,453	.011,111	.002,777,8
206,265	3,437.8	57.296	1.	.636,62	.159,155
324,000	5,400	90.	1.570,8	1.	.25
.....	21,600	360.	6.283,2	4.	1.

TIME—(MEAN SOLAR).

SECONDS	MINUTES	HOURS	DAYS	WEEKS	MONTHS (AVERAGE)	YEARS (365 DAYS)
1	.016,67	.000,278	.000,011,6	.....	.....	.....
60	1	.016,67	.000,694,4	.000,099,2	.....	.....
3,600	60	1	.041,667	.005,952,4	.001,37	.000,114
86,400	1,440	24	1.	.142,86	.032,88	.002,74
604,800	10,080	168	7.	1.	.230,14	.019,18
.....	43,800	730	30.417	4.345,24	1.	.083,33
.....	525,600	8,760	365.	52.143	12.	1.

PAPER MEASURE.

SHEETS	QUIRES	REAMS
1	.041,67	.002,08
24	1.	.05
480	20	1.

TABLE OF UNITS.

UNITS	DOZEN	GROSS	GREAT GROSS
1	.083,33	.006,944	.000,578,7
12	1.	.083,33	.006,944
144	12.	1.	.083,33
1,728	144.	12.	1.

MONEY EQUIVALENTS—(GOLD BASIS).

DOLLARS 100 CENTS U. S. AND CANADA	POUNDS 20 SHILLINGS GREAT BRITAIN	FRANCS 100 CENTIMES FRANCE	MARKS 100 PFENNIG GERMANY	RUBLES 100 KOPECKS RUSSIA	PESOS 100 CENTAVOS MEXICO (SILVER STAN'D)	PESOS CUBA
1.	.2055	5.18	4.20	1.942	2.611	1.080
4.8665	1.	25.21	20.44	9.451	12.706	5.256
.193	.0396	1.	.811	.375	.504	.208
.238	.0489	1.233	1.	.462	.621	.257
.515	.1058	2.668	2.163	1.	1.345	.556
.383	.0787	1.984	1.609	.744	1.	.414
.926	.1901	4.797	3.889	1.798	2.418	1.

IV. COMPOUND EQUIVALENTS.

VELOCITIES.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Feet per Second. .	Meters per Second...	82	25	.3048	3.2808
Feet per Second. .	Miles per Hour.	22	15	.6818	1.4667
Feet per Second. .	Knots per Hour. . . .	76	45	.5921	1.6889
Feet per Second. .	Kilometers per Hour.	41	45	1.0973	.9113
Feet per Minute...	Miles per Hour.	264	3	.0114	88.
Miles per Hour. . .	Meters per Second...	85	38	.4470	2.2369
Knots per Hour . .	Kilometers per Hour.	34	63	1.8533	.5396

WEIGHTS, LENGTHS, ETC.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Pounds (Avoird.) per Mile.	Grains per inch	190	21	.1105	9.0514
Pounds (Avoird.) per Mile.	Kilograms per Kilometer.	540	152	.2818	3.5480
Pounds (Avoird.) per Yard.	Kilograms per Meter	230	114	.4961	2.0159
Pounds per Foot (Steel).	Square Inches Section	630	185	.2939	3.4017
Pounds per Yard (Steel).	Square Inches Section	500	49	.0980	10.205
Pounds per Yard .	Tons (Long) per Mile.	14	11	.7857	1.2727
Circular Mils (Copper).	Pounds per 1000 Feet	18,500	56	.00303	330.3
Circular Mils (Copper).	Pounds per Mile	125	2	.01598	62.56

CAPACITIES AND WEIGHTS.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Pounds per Cu. Inch	Grams per Cu. Centimeter	6	166	27.680	.0361
Pounds per Cu. Foot	Grains per Cu. Inch	40	162	4.0509	.2469
Pounds per Cu. Foot	Pounds per Gallon (U. S. Liquid)	30	4	.1337	7.4805
Pounds per Cu. Foot	Tons (Short) per Cu. Yard	2,000	27	.0135	74.074
Pounds per Cu. Foot	Kilograms per Cu. Meter	181	2,900	16.018	.0624
Tons (Short) per Cu. Yard	Metric Tons per Cu. Meter	75	89	1.1866	.8428

PRESSURES.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Pounds per Sq. Inch	Tons (Short) per Sq. Foot	1,000	72	.0720	13.889
Pounds per Sq. Inch	Tons (Long) per Sq. Foot	700	45	.0643	15.556
Pounds per Sq. Inch	Metric Tons per Sq. Meter	64	45	.7031	1.4223
Pounds per Sq. Inch	Atmospheres	485	33	.0680	14.697
Pounds per Sq. Inch	Feet of Water	52	120	2.3067	.4335
Pounds per Sq. Inch	Millimeters of Mercury	89	4,600	51.712	.01934
Pounds per Sq. Inch	Inches of Mercury	56	114	2.0359	.4912
Pounds per Sq. Foot	Kilograms per Sq. Meter	43	210	4.8824	2.048
Tons (Short) per Sq. Foot	Metric Tons per Sq. Meter	43	420	9.7648	.1024
Feet of Water	Pounds per Sq. Foot	25	1,560	62.428	.0160
Feet of Water	Atmospheres	610	18	.0295	33.901
Inches of Mercury	Atmospheres	4,100	137	.0334	29.921

WORK.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Foot-pounds	Joules	45	61	1.3557	.7376
Foot-pounds	Calories (Small)	68	22	.3239	3.0878
Foot-pounds	Kilogram Meters	600	83	.1383	7.2330
Horse-power Hours	Kilowatt Hours	59	44	.7457	1.3411
Horse-power Hours	Calories (Small)	92	59	.6412	1.5595
B. T. U.	Foot-pounds	9	7,000	778.1	.001285
B. T. U.	Kilowatt Seconds	18	19	1.0549	.9480
B. T. U.	Calories (Large)	690	174	.2520	3.9683
B. T. U.	Horse-power Seconds	41	58	1.4147	.7068
B. T. U.	Metric Horse-power Seconds	23	33	1.4344	.6972
B. T. U.	Watt Hours	58	17	.2930	3.4127

MONEY, LENGTH, WEIGHT, ETC.

SCALE C	SCALE D	SCALE C	SCALE D	IF C= 1, D=	IF D= 1, C=
Cents per Ounce (Avoird.)	Dollars per Pound (Avoird.)	100	16	.160	6.25
Dollars per Ton (Short)	Francs per Metric Ton	10	57	5.70	.175
Dollars per Ton (Long)	Francs per Metric Ton	10	51	5.10	.196
Dollars per Pound (Avoird.)	Marks per Kilogram	108	1,000	9.26	.108
Cents per Yard	Francs per Meter	1000	56	.056	17.64
Dollars per Mile	Shillings per Mile	73	300	4.11	.243
Dollars per Mile	Francs per Kilometer	59	190	3.22	.311

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1777.	The Union Slide Rule (Mannheim), 10 in., divisions on white ivorine, with glass indicator; printed instructions with Rule.....Each,	3	60
1787.	The Engineers' Slide Rule, 24 in., Hardwood, with directions.....Each,	5	00
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